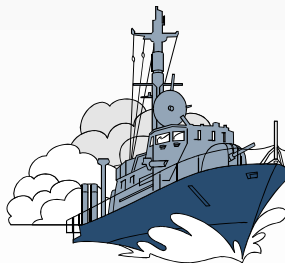
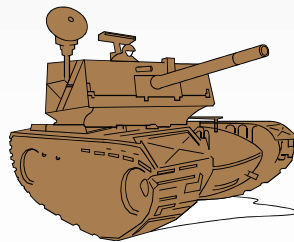
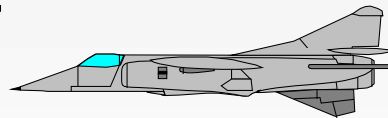
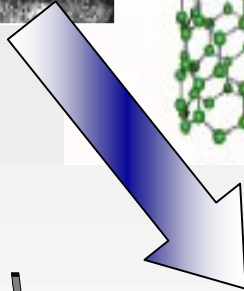
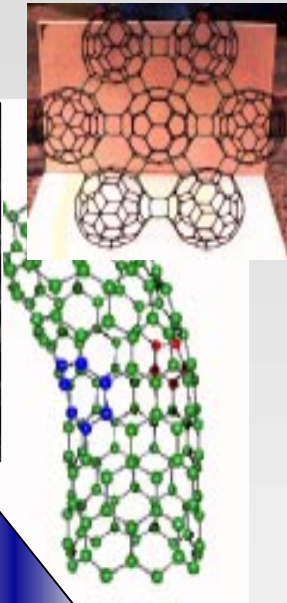
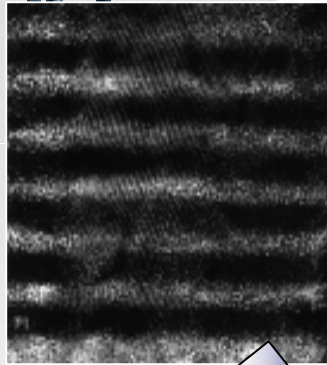
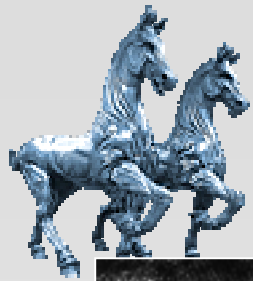
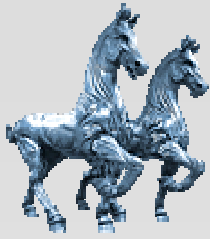


# Directions and Opportunities in DARPA's Materials Program

Steven G. Wax

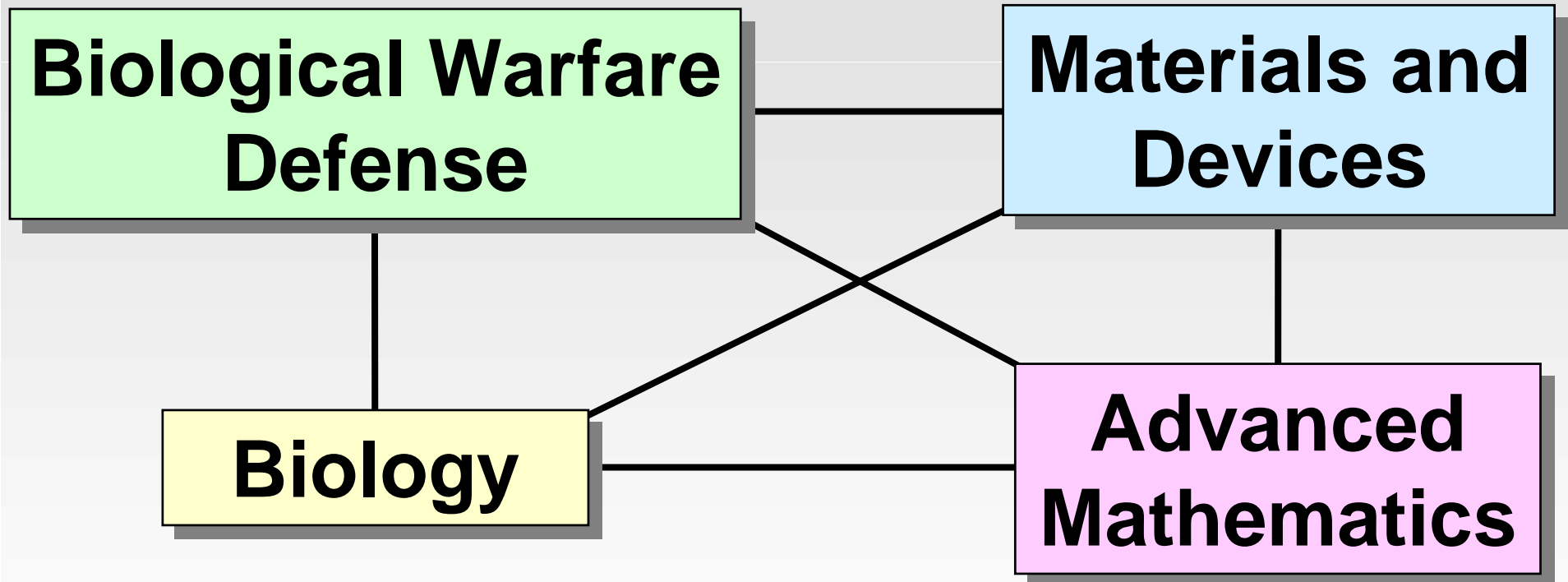


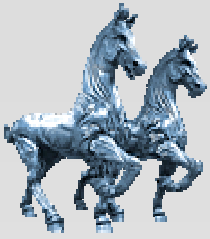
***DSO***



# DSO Program Synergism

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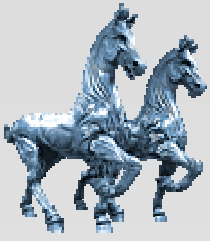




# Materials and Devices

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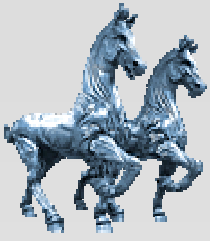
- Smart Materials and Demonstrations
  - Garcia, Coblenz, Wax
- Structural Materials and Components
  - Wax, Coblenz, Christodoulou, Lyons
- Functional Materials and Devices
  - Wolf, Warren, Browning
- Mesoscopic Machines
  - Warren, Wax
- Power Generation and Storage
  - Nowak, Wax



# Materials Synergies

---

- Biology
  - Biomimetic Materials
    - Rudolph, Wax, Christodoulou
- Defense Applications of Advanced Mathematics
  - Virtual Integrated Prototyping
    - Healy, Wolf



# Program Philosophy

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## New Concepts in Materials

Enabling

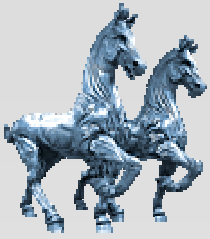
## Emerging Defense Needs

- Rapid Design and Prototyping
- Micro/nanostructure Control
- Computational Materials Science
- Combinatorial Synthesis
- Biomimetics
- Multi-functionality

- Force Projection, Mobility
- Littoral Operations
- Information Driven Warfare
- Aging Platforms
- Small Units, Urban Warfare
- Unmanned Systems
- Nuclear/Chem/Bio Threat

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***DSO***

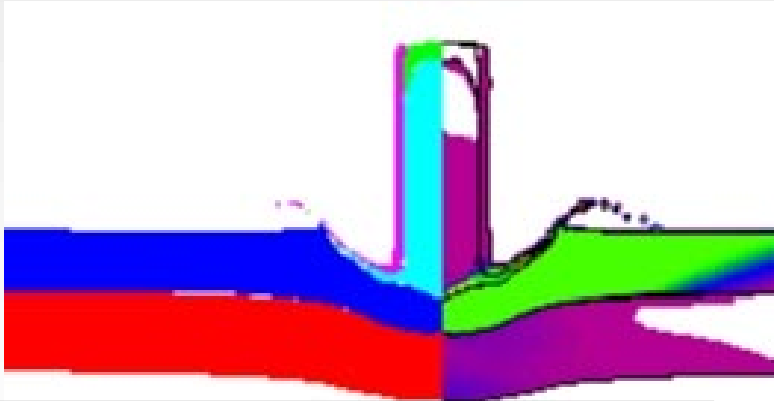


# Ultra-lightweight Armor Program

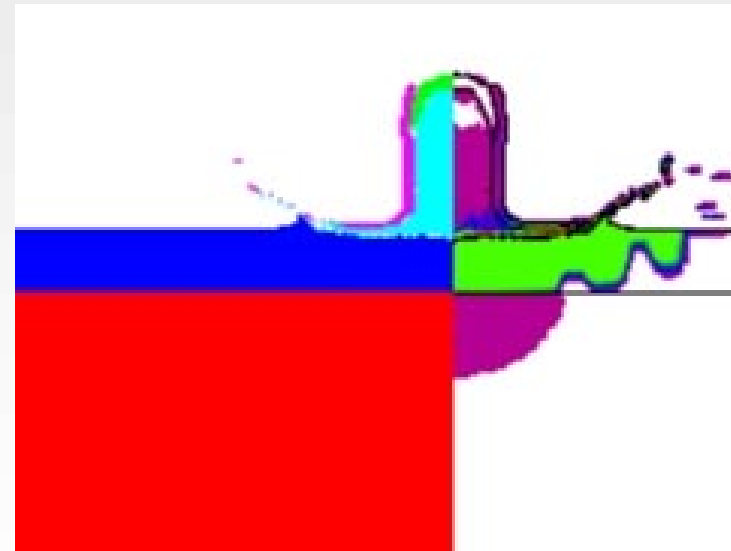
---

Establish New Designs for Body Armor Material Systems

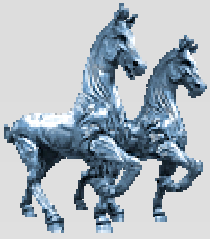
- **Target: 3.5 lbs/ft<sup>2</sup>** (7.62 mm AP) vs. Current 6.5 lbs/ft<sup>2</sup>
- Exploiting New Mechanisms
- Understanding/Predicting Behavior (Model→Test)



5.08-mm B<sub>4</sub>C/6.60-mm Al



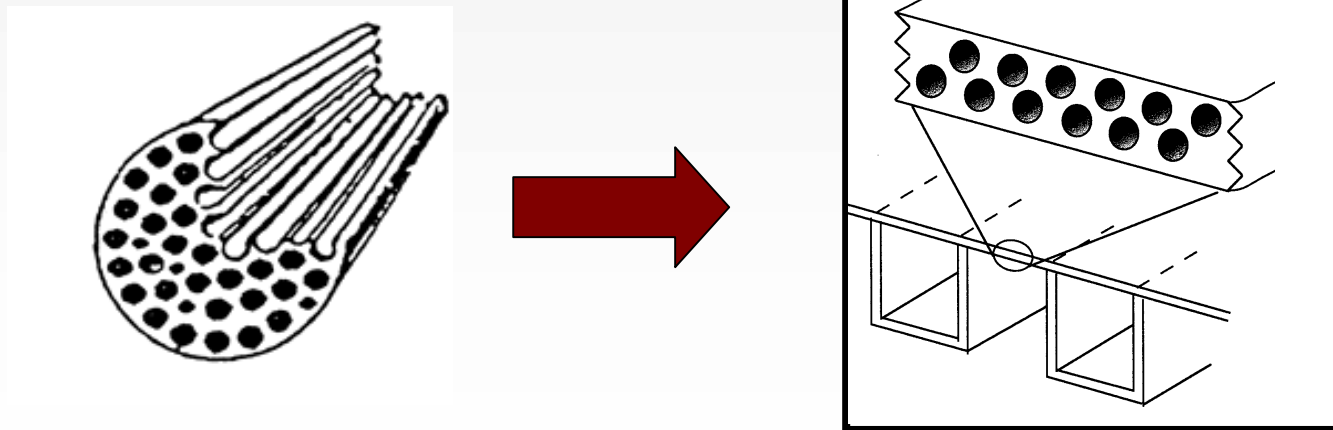
5.08-mm B<sub>4</sub>C/ **Semi-inf.** RHA



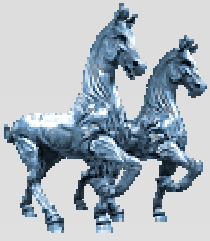
# Multi-Functional Materials and Structures

---

- Designed Compositional and Morphological Arrangements
  - Perform Multiple Functions Simultaneously (Often Inspired by Nature)
- New Paradigm for Structure Design
  - Significant Impact on DoD Systems Performance, Survivability and Maintenance

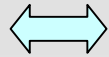


***DSO***

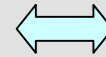


# Smart Materials and Structures

**Material  
Development**



**High Authority  
Actuators**



**Demonstrations**

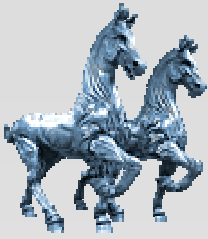
- Single Crystal Perovskites
- Electroactive Polymers
- Shape Memory Alloys
- Piezoelectrics
- Electrostrictors
- Magnetostrictors

- Helicopter
- Fixed Wing Aircraft
- Submarines/  
Torpedo



***DSO***





# Electroactive Polymers

**Tailorable,  
Responsive  
Electroactive  
Properties**

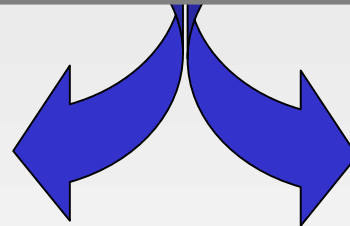


**Polymer  
Chemistry**

**Structural  
Properties of  
Polymers**



**Actuation  
and Sensing**

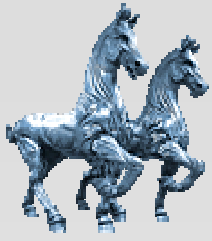


**Electro-Optical  
Response**

**Artificial Muscles and Smart Skins  
Acoustic (Sonar)  
Biomimetic Devices**

**Analog Processing  
Flexible Displays  
Flexible Electronics**

**Electroactive Polymers are  
“Intrinsically” Smart Materials**

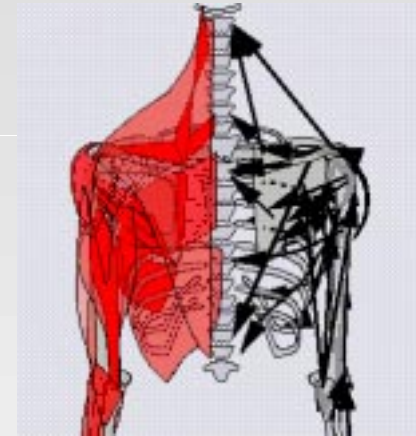


# Electroactive Polymers Actuation

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- Promise

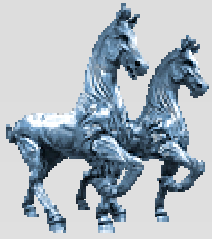
- Bio-Inspired Actuation  
(Mammalian Muscle)
- Microactuation



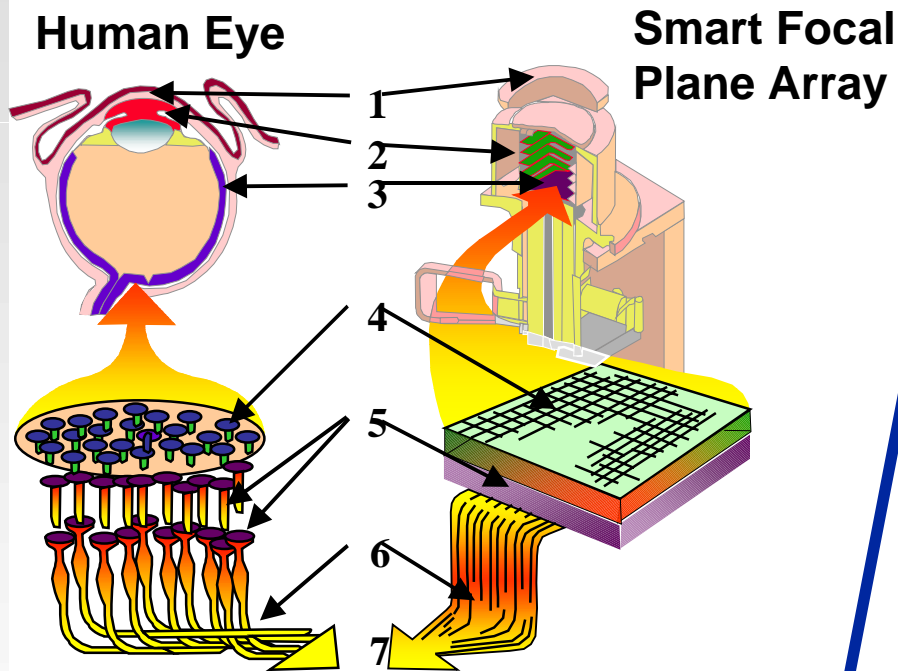
- Advantages:

- Compactness
- Low Overhead
- Intrinsic Sensor Capability
- Localize Actuation Control

***DSO***

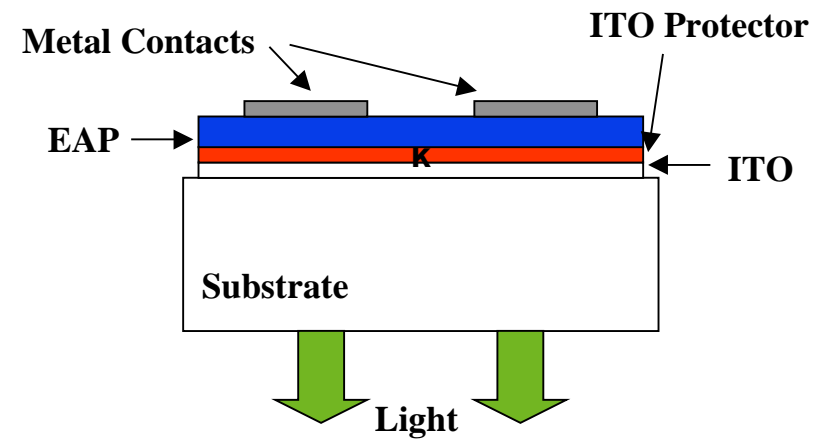


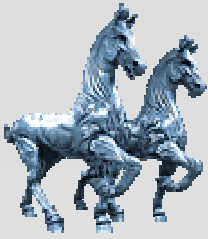
# Electroactive Polymers Applications



Artificial Retina  
(Uniax, Ratheon)

## Green Light Emitting Polymer (Dow Chemical)

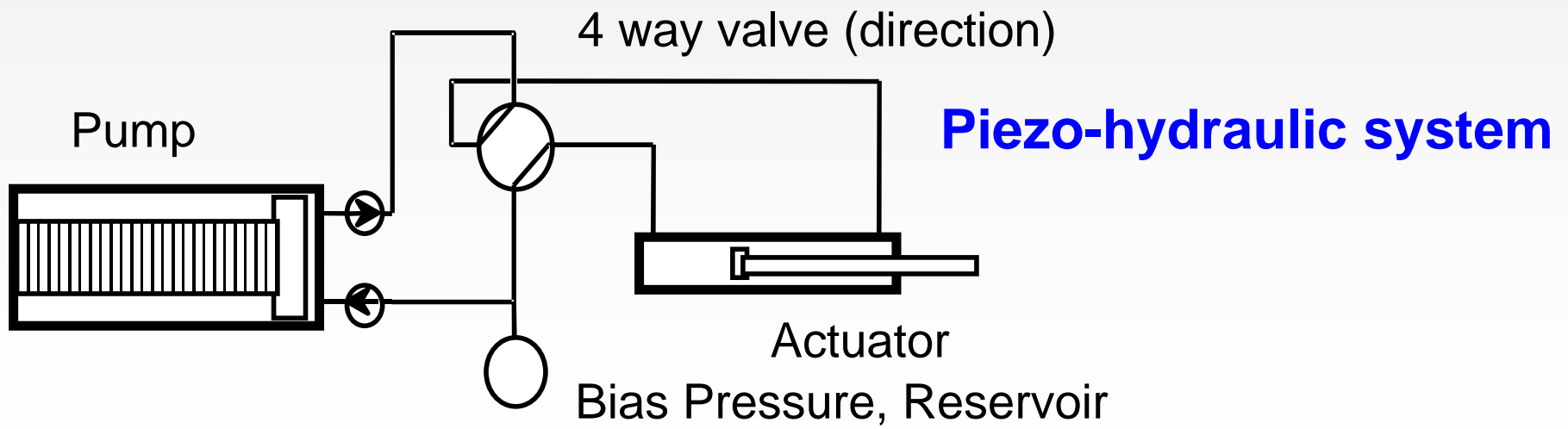


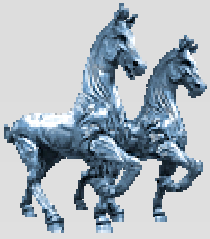


# Compact Hybrid Actuation

---

- System Level, Concurrent Design
    - Mechanical & Electrical Transmissions
    - Power Electronics
    - Controllers
    - Fatigue, Reliability & Durability
- 





# POWER SYSTEMS MATERIALS & PROCESSES

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## ***POWER SOURCE DEVELOPMENT DEPENDS ON NEW MATERIALS***

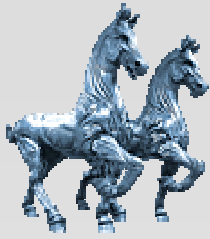
- Electrodes, Electrolytes
- Catalysts
- Emitters
- Filters
- MEMs
- Seals, Interconnects
- Superconductors
- Thermoelectrics
- Photovoltaics
- Permanent Magnets



- Batteries
- Fuel Cells
- Capacitors
- TPV, Solar
- Microturbines
- Heat Engines
- Motors
- Energy Harvesting

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***DSO***



# World's Smallest Turbine Engines

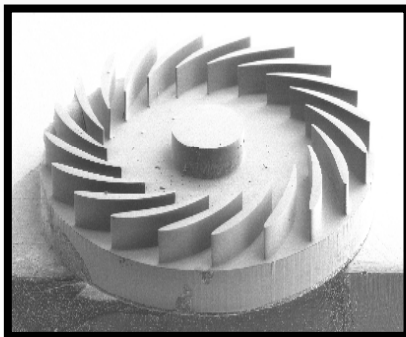
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- Current: Gas Turbine Driven, Electric Power Generator

- Quiet.....Field Deployable
- Powerful.....1 kW Class/1.3 shp
- Portable.....Less Than 1 kg
- Miniature.....The Size of a Soda Can
- Efficient.....3 hr on a Liter of Heavy Fuel
- Robust.....Multi-Fuel/Low Maintenance



M-Dot, Inc



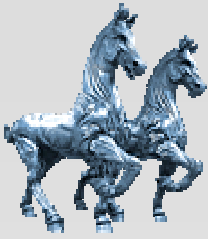
MIT

- Future:  $>2$  kW-hr/kg



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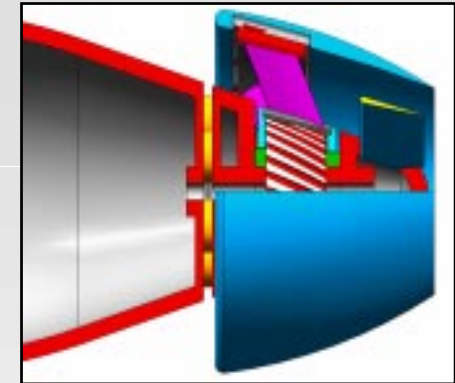
***DSO***



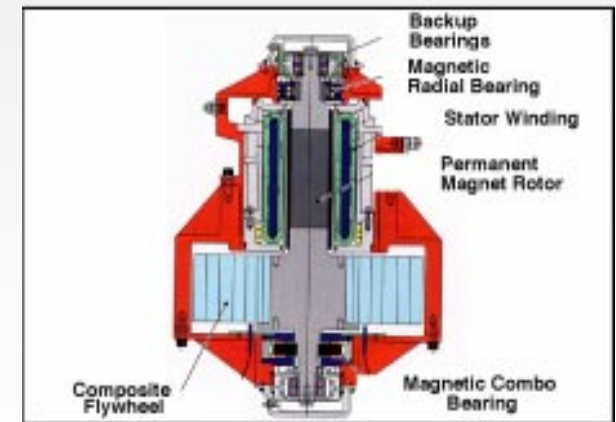
# Advanced Magnets for Power

- Magnetic Alloys and Compounds for Advanced Power Systems
  - High Energy Products (100 MGOe)
  - High Temperature Operation ( $>250$  C)
  - Mechanical Strength

*YBM Magnex, Inc. Has Already Shown a 20% Improvement in Energy Product With a New FE-B-H Alloy*

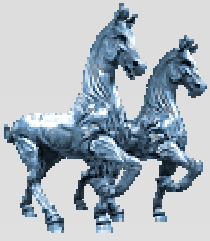


*Integrated Motor Propulsor*



*Flywheel for Combat Hybrid Power Systems (CHPS)*

**DSO**



# ENERGY HARVESTING

(mW'S - W'S)

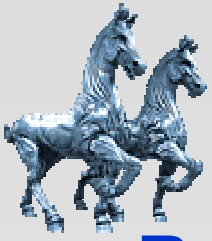
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- Photovoltaics
  - Thin-film Manufacturing
- Mechanical
  - Ocean Currents, Heel Strike
- Thermal
  - Ground-air, Ocean-air Interfaces
- Chemical Gradients
  - Ocean Sediments
- Natural Fuels
  - Cellulose, Plant Sugars, Blood Sugar

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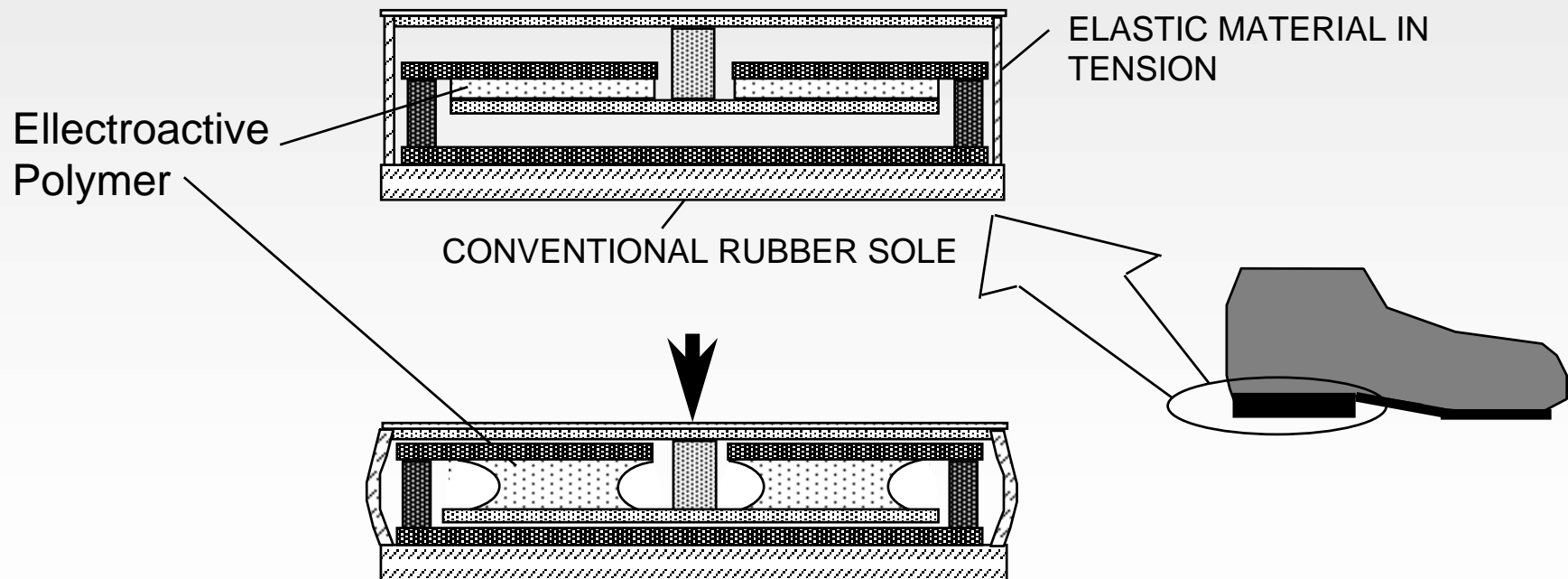
***DSO***

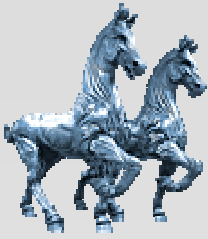




# Heel-strike Generator

- Recover up to Several Watts of Power During Normal Walking Without Burdening the Wearer
- Power Is Used to Charge Batteries or Directly on Boot for Specialized Functions





# Mechanical Augmentation of Human Capabilities

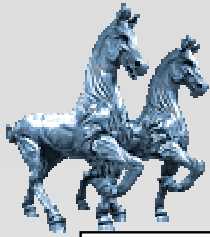
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- Move at the Speed of Battle in All Terrains
- Enhanced Load Carrying Capability
- Efficient Power Usage, Easy Re-fueling

## Technology Issues

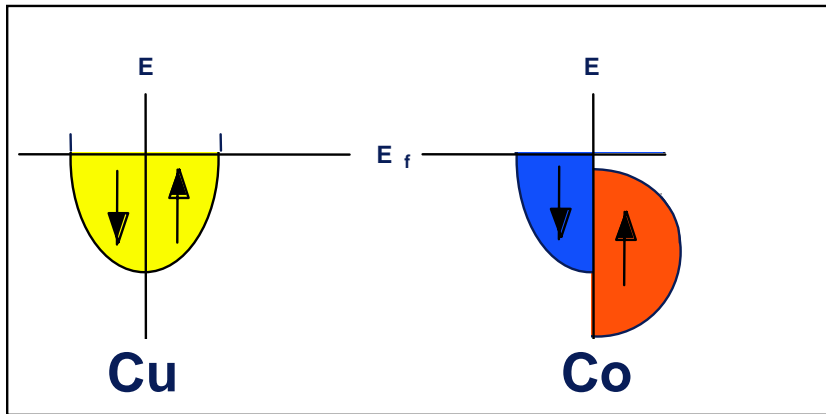
- Smart, Efficient Actuators
- Non-battery Power Sources, Power Distribution
- Sensors, Feedback, Control
- Reliability and Cost



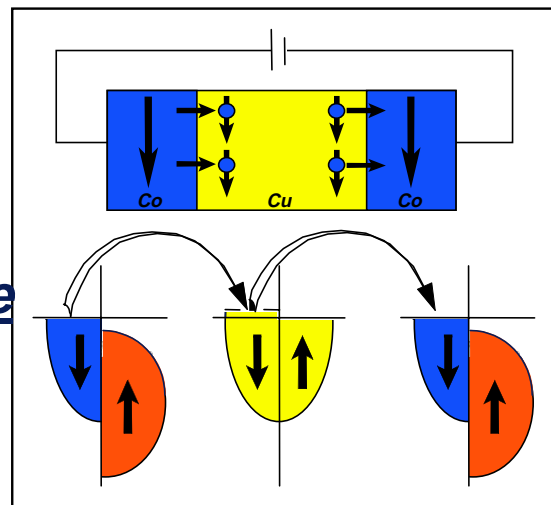
# Spintronics

A New Approach  
to Electronics!

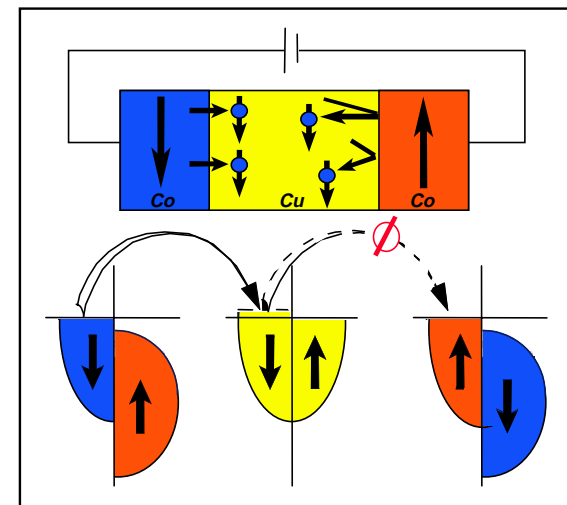
Metallic Energy States



Spin  
Magnetoresistance

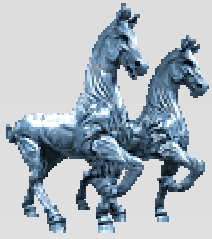


Low Resistance



High Resistance

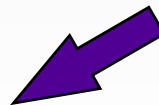
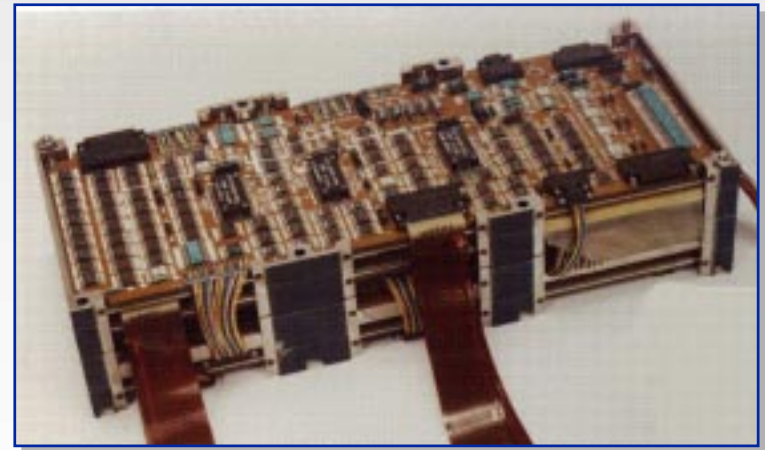
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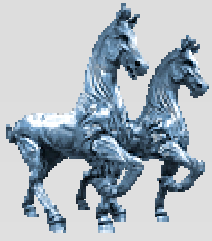


# Spintronics for Magnetic Memory

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- Non-Volatile, Radiation Hard Memory for Space, Missile and Avionics Applications
  - Speed of SRAM ( $<3$  ns)
  - Density of Dram (4 Gbit)
  - Low Power (0.1 - 0.01x)
  - Low Cost (0.1x)
  - Infinitely Cyclable





# Coherent Spins in Semiconductors

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- Discoveries:

- Room Temperature, Optically Induced, Very Long Lived Quantum Coherent Spin State in Semiconductors (UCSB, 1997-1999)
- Ferromagnetism in Semiconducting GaMnAs (Sendai, Japan 1998)



- Potential Applications

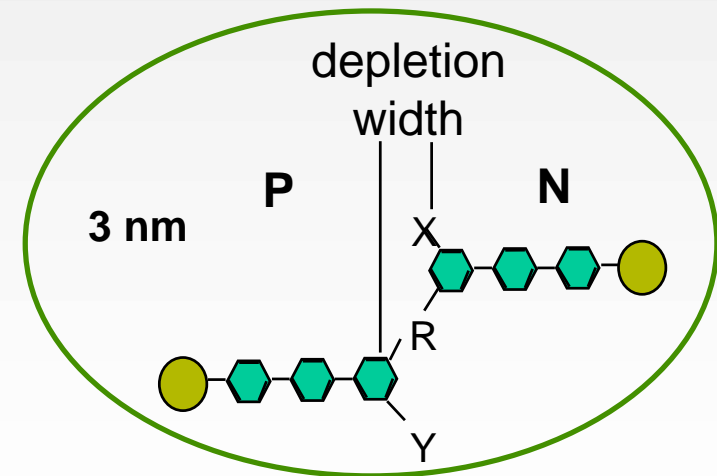
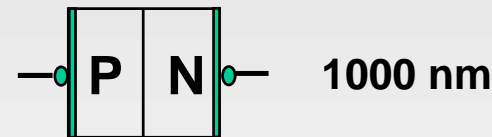
- Quantum Computing in Conventional Semiconductors
- Very Fast, Very Dense, Low Power Memory and Logic
- Magnetic Sensors With SQUID Like Performance
- Optical Encoders and Decoders

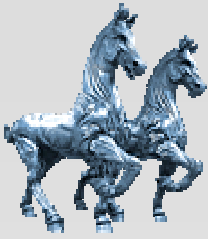
***DSO***



# Molecular Electronics (Moletronics)

- Self-assembled Miniaturized Computational Engine Using Molecular Electronics
- Attributes
  - 3-D
  - High Density
  - Room Temperature
  - Low-power
  - Compact
  - Self-assembled
  - Requires Fault-tolerance





# Nanotechnology

**“Small is Different”**

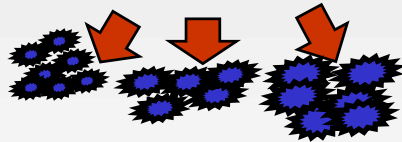
Ferromagnets => Superparamagnets

Ferroelectrics => Superparaelectrics

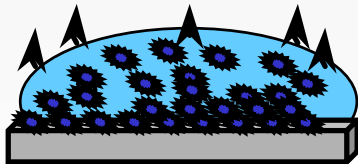
Semiconductors => Quantum Dots

Metals => Coulomb Islands

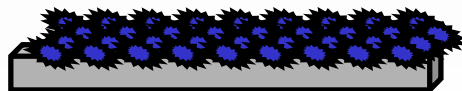
## Size Selective Processing



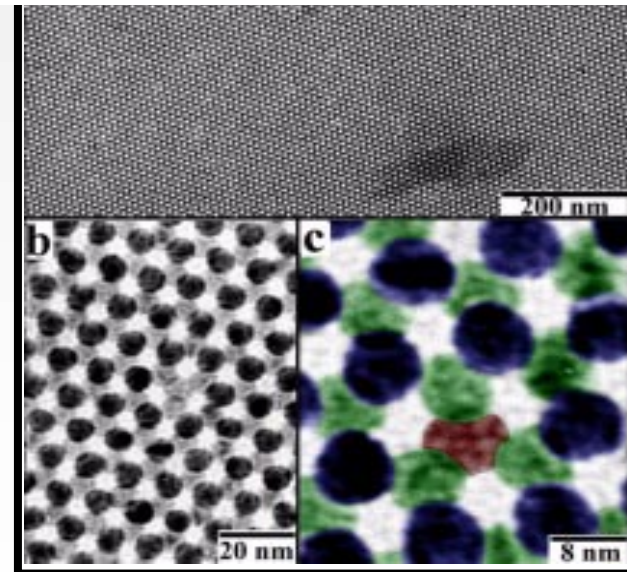
## Film Growth: Self-Assembly



## Nanocrystal Superlattice

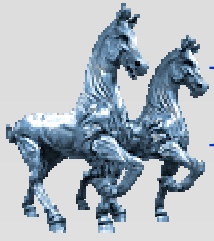


## Superlattice of 8 nm Cobalt Nanocrystals



Murray  
IBM

**DSO**

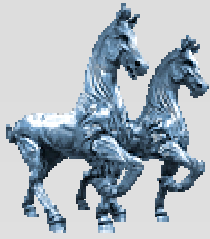


# Multi-scale Design and Integration

---

- For Multi-scale (mm to nm) Devices
  - Conventional Subsystems, Mesomachines, MEMS, and Evolving Nano-scaled Technologies
  - e.g., Hybrid Power Management Systems
- Functional Integration To Maximize Efficiency
  - Power, Actuation, Fluids, Electronics, Structure, etc.



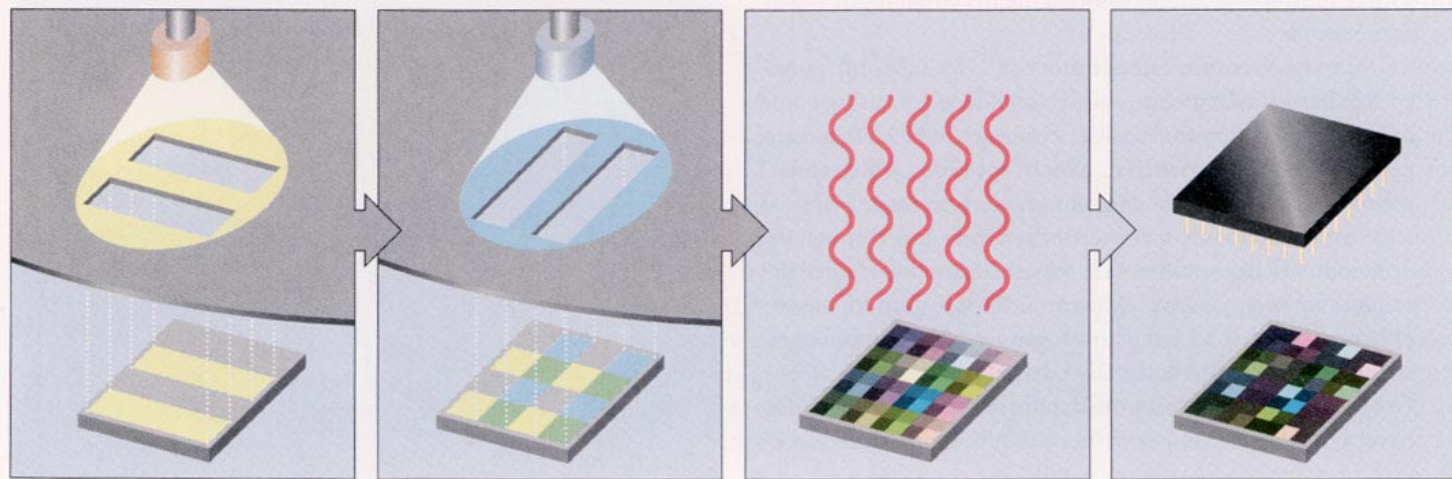


# Combinatorial Synthesis

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**Deposit** large library of  
inorganic compounds

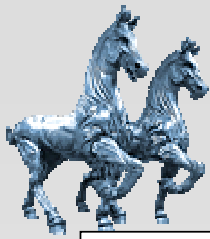
**Process**   **Measure** properties  
(T, P, t, etc.)



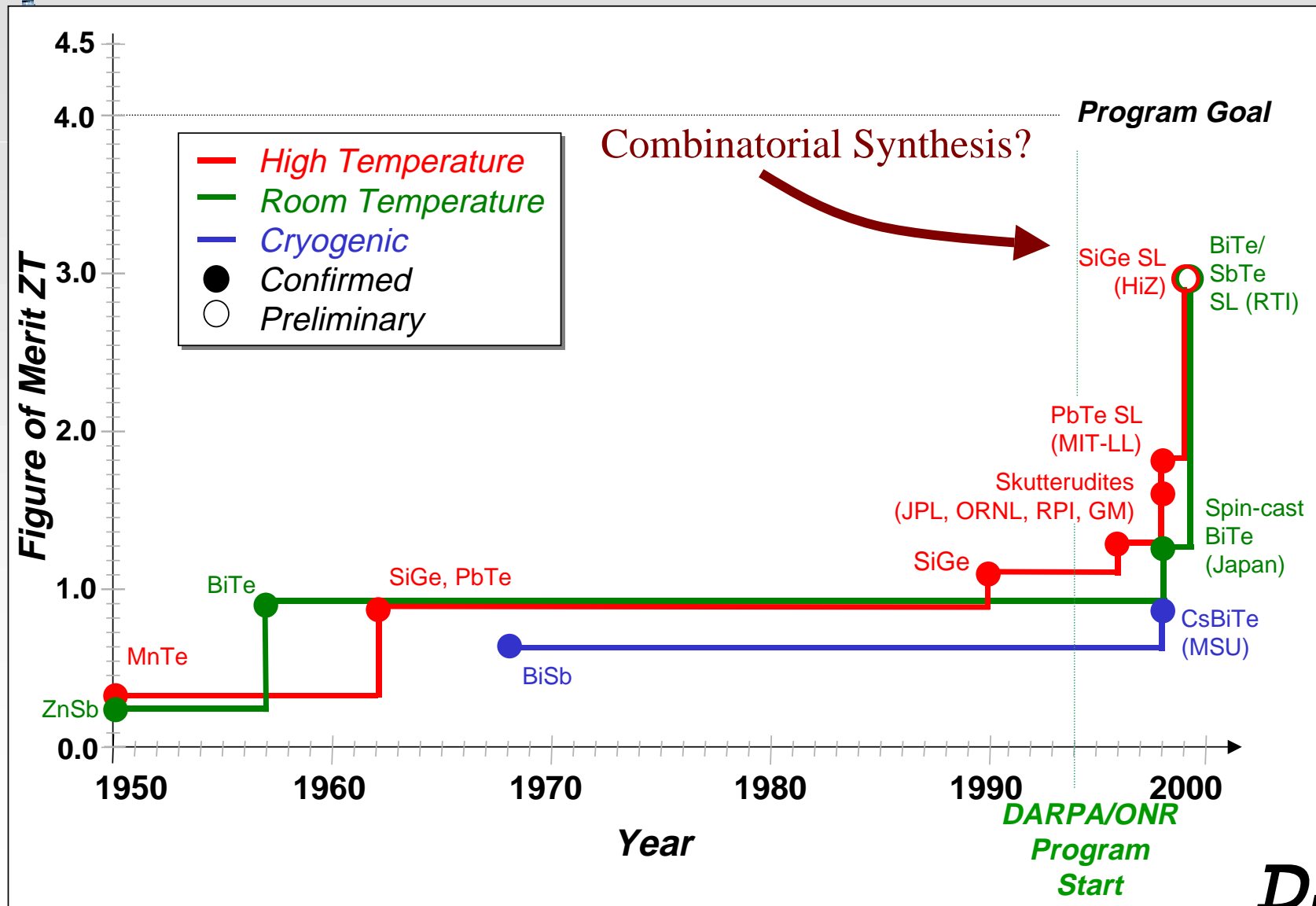
- Accelerate the Discovery of New Materials
- Determine Optimum Processes and Synthesis
- Rapid Diagnostics Is The Key!

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**DSO**

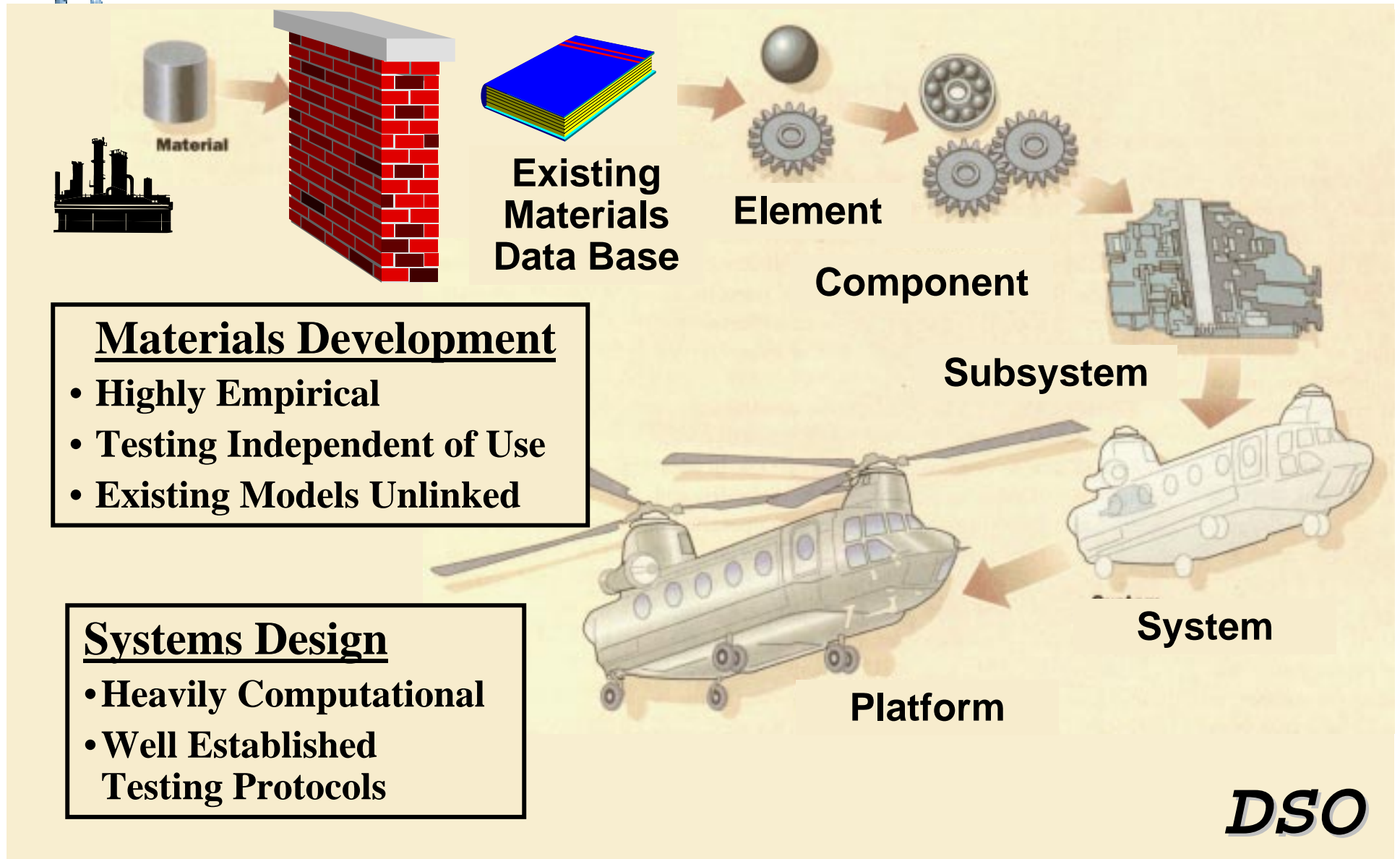


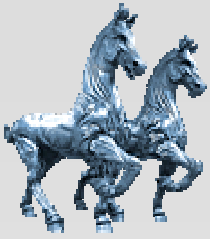
# Thermoelectrics





# The Dilemma in Materials Development!



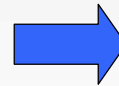


# Accelerated Insertion

- Modeling **and** Experiment in the Optimal Construction of a “Database” That Satisfies **Designers** Needs

Properties	Conditions			
	P1	C1	C2	C3
	P2	C1	C2	C3
	P3	C1	C2	C3
	Pn	C1	C2	Cn

Experimental   
Virtual 



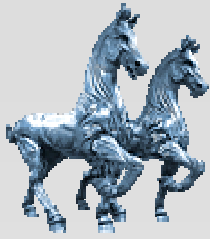
Reliable Manufacturing Process

Predictable Properties

Predictable Life-Cycle Costs

Maximum, Reliable Performance

***DSO***



# Growing/Emerging Opportunities

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- Multi-Functional Materials
- Electroactive Polymers
- Compact Hybrid Actuation
- Mechanical Enhancement of Human Capability
- Advanced Magnetic Materials
- Spin Electronics
- Molecular Electronics
- Nanostructured Materials -- Applications Driven!
- Small Scale Design and Integration
- Accelerated Insertion of Materials